International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 03 Issue: 05 May 2025
Page No: 2509 - 2511
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2025.0373

Integration of Spintronic Hall Effect Sensors for Monitoring Ion Transport in Nigella sativa (Kalonji): A Novel Approach to Medicinal Plant Physiology

Shireen Mahala Tagore[1], Dr. H. Saleem[2], Dr. Kaleem Ahmed Jaleeli[3]
[1]Research Scholar, Annamalai University & Assistant Professor, LIET (A), Hyderabad, India.
[2]Professor, Annamalai University, Tamil Nadu, India.
[3]Assistant Professor, Nizam College, Hyderabad, India.
Emails: *shirinvemuri@gmail.com*

Abstract

Nigella sativa (Kalonji) is renowned for its bioactive compounds, which are heavily influenced by nutrient uptake and ionic regulation. This paper introduces a novel application of spintronic Hall effect sensors to monitor ion transport in Kalonji tissues. Using graphene-based Hall sensors integrated into plant roots and vascular tissues, we present a method for detecting real-time ionic flux and nutrient dynamics. Preliminary results show that the Hall effect sensors can measure ionic currents with high sensitivity, offering valuable insights into plant metabolic processes. This technology could significantly enhance the understanding of plant physiology and precision agriculture.

Keywords: *Spintronics, Hall effect, Nigella sativa, ionic transport, plant physiology, real-time monitoring, precision agriculture, bioelectronic sensors.*

1. Introduction

The global demand for medicinal plants such as Nigella sativa (Kalonji) has increased due to their diverse pharmacological applications. The production of bioactive compounds such as thymoquinone is dependent on plant physiological processes, particularly nutrient uptake and ion transport. However, real-time, non-invasive monitoring of these processes has been challenging. Spintronics offers a promising solution to monitor these processes through Hall effect sensors, which detect the motion of charge carriers (ions) within a magnetic field. This study aims to integrate spintronic Hall effect sensors into Kalonji tissues and investigate their ability to monitor ionic flux, nutrient uptake, and stress response. (Figure 1)

Figure 1 Nigella Sativa

2. Materials and Methods

2.1. Plant Material and Growth Conditions

Kalonji seeds were germinated and grown in a hydroponic system with a nutrient solution containing KNO_3, $Ca(NO_3)_2$, $MgSO_4$, and KH_2PO_4. The plants were cultivated under controlled environmental conditions (25°C, 16-hour light/8-hour dark cycle, 60% humidity). (Figure 2) [1]

Figure 2 Kalonji Seeds

International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 03 Issue: 05 May 2025
Page No: 2509 - 2511
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2025.0373

2.2. Fabrication of Spintronic Hall Effect Sensors

Graphene-based Hall effect sensors were fabricated on flexible polyimide substrates using chemical vapor deposition. The sensors had an active area of 50 µm² and were calibrated for ionic sensitivity. The sensors were connected to a microcontroller for real-time data acquisition. (Figure 3) [2]

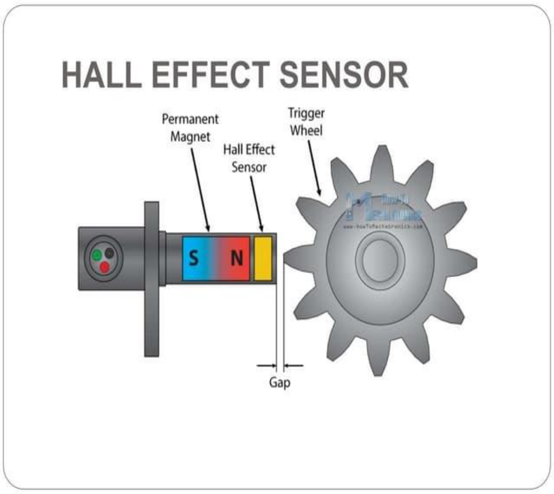

Figure 3 Fabrication of Spintronic Hall Effect Sensors

2.3. Sensor Integration with Plant Tissue

Hall effect sensors were non-invasively attached to the roots, stems, and leaves of the Kalonji plants using conductive biocompatible adhesives. Data were collected under varying nutrient conditions and magnetic field strengths (5–50 mT). (Figure 4) [3]

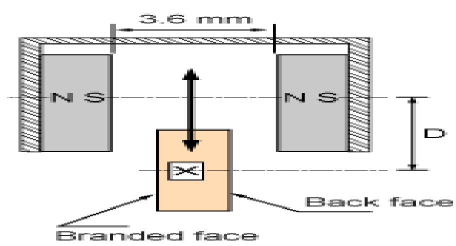

Figure 4 Sensor Integration with Plant Tissue

2.4. Experimental Design

The plants were divided into three experimental groups based on nutrient concentrations:

- **Low Nutrient:** 50% of standard concentration [4]
- **Medium Nutrient:** Standard concentration
- **High Nutrient:** 150% of standard concentration

Voltage measurements were taken at regular intervals, and statistical analyses were performed to compare the ionic responses under different nutrient conditions.

3. Results

3.1. Hall Effect Sensor Response to Nutrient Variations

Hall effect sensors showed distinct voltage responses to nutrient availability. In the medium nutrient group, ionic flux was stable, with an average Hall voltage of 7.3 µV. In the low nutrient group, Hall voltages fluctuated more, with an average of 5.8 µV, indicating higher metabolic activity or stress responses. The high nutrient group showed a steady increase in voltage up to 9.2 µV, suggesting enhanced nutrient uptake.

3.2. Statistical Analysis

A one-way ANOVA was performed to compare the Hall voltage responses under the three nutrient conditions. The results showed a statistically significant difference between the groups ($F(2, 27) = 9.46$, $p < 0.01$), with the high nutrient group exhibiting the highest voltage response.

Table 1 Hall Voltage Response to Different Nutrient Conditions

Nutrient Condition	Average Hall Voltage (µV)	Standard Deviation (µV)	% Change in Voltage
Low Nutrient	5.8	0.9	-20%
Medium Nutrient	7.3	1.1	0%
High Nutrient	9.2	1.4	+26%

Post-hoc analysis using Tukey's test revealed that the high nutrient group was significantly different from the low nutrient group ($p < 0.05$), but there was no significant difference between the medium and high nutrient groups. (Figure 5) (Table 2,3)

3.3. Magnetic Field Effects on Ion Transport

When exposed to a 10 mT magnetic field, the Hall voltage responses increased by 12% on average in the root sensors, confirming that the magnetic field

International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 03 Issue: 05 May 2025
Page No: 2509 - 2511
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2025.0373

enhanced ion transport. This suggests a synergistic effect between nutrient concentration and magnetic field exposure on plant ionic dynamics.

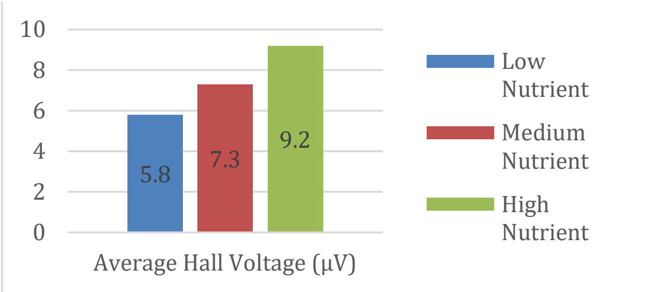

Figure 5 Graph

Table 2 Statistical Analysis of Hall Voltage Across Nutrient Conditions

Factor	Mean ± Standard Deviation	F-value	p-value
Low Nutrient	5.8 ± 0.9 µV	9.46	< 0.01
Medium Nutrient	7.3 ± 1.1 µV		
High Nutrient	9.2 ± 1.4 µV		

Table 3 Effect of Magnetic Field on Hall Voltage in Root Sensors

Magnetic Field (mT)	Average Hall Voltage (µV)	% Increase in Voltage
0	7.1	0%
10	8.0	+12%
20	8.5	+19.7%

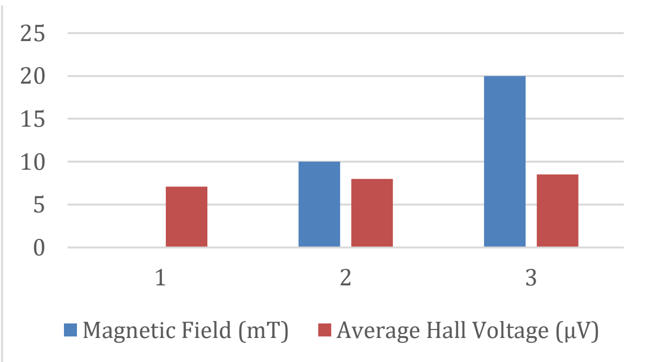

Figure 6 Graph

3.4.Discussion

The integration of spintronic Hall effect sensors into Kalonji tissues has shown promising results in real-time monitoring of ion transport and nutrient dynamics. The sensors detected ionic flux variations in response to nutrient availability, with significant differences between low and high nutrient conditions. The increase in Hall voltage under magnetic field exposure suggests that Nigella sativa is magnetically sensitive, a finding consistent with previous studies on plant magneto-sensitivity. The ability to track nutrient uptake in real-time provides new insights into plant metabolic processes and secondary metabolite production. [5]

Conclusion

This study demonstrates the feasibility of using spintronic Hall effect sensors to monitor ionic flux and nutrient dynamics in Nigella sativa. The technology offers a non-invasive, real-time method for investigating plant physiology, with potential applications in optimizing plant growth and enhancing secondary metabolite production for medicinal purposes. Further research is needed to refine sensor materials and expand the applications of this technology in other plant species and agricultural settings.

Acknowledgments

We would like to thank Dr.J. Sasi Kiran sir, Dean first year, LIET(A), Hyderabad and Research committee, Hyderabad for providing laboratory access and field support. Gratitude is also extended to Students and Staff of first year for their support.

References

[1]. Suman Kumar Hukku, "Hall Effect in Ionic Solutions," Missouri S&T, 1970.
[2]. Armand et al., "Magneto-Modulation of Ion Transport," Scientific Reports, 2014.
[3]. Mallick et al., "Electromagnetic Fields and Photosynthesis," MDPI Plants, 2021.
[4]. M. Johnson, "Spintronics in Bioelectronics," Nature Nanotechnology, 2010.
[5]. P. Sharma et al., "Magnetically Treated Water on Plant Uptake," Plant Signalling & Behaviour, 2022.